CODE ENHANCED EQUALIZATION BASED UPON A RELIABILITY FACTOR

<u>Related Applications</u>

This application contains disclosure similar to the disclosure in U.S. Application Serial No. 09/052,501 filed March 31, 1998.

<u>Technical Field of the Invention</u>

The present invention relates to an arrangement for decoding transmitted data and for using the decoded data to enhance the operation of an equalizer.

<u>Background of the Invention</u>

An equalizer is typically used in receivers to reduce noise and communication channel effects which would otherwise make the accurate recovery of transmitted data difficult. Equalizers are frequently implemented as time domain filters which multiply received signals by a plurality of taps and which sum the multiplication results to produce corresponding equalizer outputs. The values of an equalizer's taps are adjusted during operation of the

equalizer to optimize the equalizer's performance.   Feed
forward or feedback control may be used for the tap value
adjustment.

In a feed forward approach, a channel estimator
may be used to estimate the channel, and the values of the
equalizer's taps are modified based upon the estimated
channel.   In a feedback approach, an output of the equalizer
is compared either with a training signal or with decoded
data, although both may be used.   If both a training signal
and decoded data are used, the training signal may be used
at start up because the initial values of the equalizer's
taps may not otherwise permit the equalizer to converge on
its optimized tap values.   Once convergence is achieved,
decoded data may be used to maintain convergence.   That is,
assuming that the equalizer is operating optimally, decoded
data downstream of the equalizer should be the transmitted
data and can be used as feedback in order to control the
values of the equalizer's taps.

During periods of time varying noise conditions
within the communication channel, however, the equalizer can
lose its convergence.   During such periods, stabilization of
the equalizer's behavior can be attempted by permitting the

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equalizer to coast until the noise condition has dissipated. As the equalizer coasts, however, the equalizer can drift away from its optimized tap values.

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The present invention is directed to an arrangement which effectively controls the tap values of an equalizer even during periods of time varying noise conditions.

Summary of the Invention

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In accordance with one aspect of the present invention, a receiver comprises an equalizer, a decoder, an encoder, an error generator, and a controller. The decoder decodes data from a signal, and the signal is based upon an output of the equalizer. The encoder re-encodes the decoded data. The error generator generates an error based upon the

15
signal and the re-encoded data and weights the error according to a reliability that the decoder accurately decoded the data from the signal. The controller controls the equalizer in response to the weighted error.

In accordance with another aspect of the present

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invention, an electrical signal represents a plurality of first data elements. A first portion of the first data

elements designates a sign, a second portion of the first

data elements designates a plurality of second data

elements, and a third portion of the first data elements

designates a plurality of third data elements. The

5   electrical signal includes a plurality of fourth data

elements derived from the sign and the second and third data

elements.

In accordance with still another aspect of the

present invention, a method comprises decoding data from a

10   data signal, wherein the data signal is based upon an output

of an equalizer; re-encoding the decoded data; providing a

feedback signal based upon the data signal, the re-encoded

data, and a reliability that the decoding of the data from

the data signal is performed accurately; and, controlling

15   the equalizer in response to the feedback signal.

Brief Description of the Drawings

These and other features and advantages of the

present invention will become more apparent from a detailed

consideration of the invention when taken in conjunction

20   with the drawings in which:

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Figure 1 is a block diagram of a transmitter which may be used in conjunction with the present invention;

Figure 2 is an exemplary Kerdock code vector that may be transmitted by the transmitter of Figure 1;

5   Figure 3 is a block diagram of a receiver which may be used in conjunction with the present invention;

Figure 4 shows the Kerdock decoder of Figure 3 in additional detail;

Figure 5 illustrates an exemplary set of
10   transformed vectors provided as an output of the Walsh Transforms of Figure 4;   and,

Figure 6 illustrates an exemplary set of reliability weighting levels r which can be provided by the Kerdock decoder of Figure 3.

15   <u>Detailed Description</u>

A hard slicer is typically used to threshold the output of an equalizer. The hard slicer applies fixed decision boundaries to the output of the equalizer in order to map the equalizer's output to corresponding data. Gain
20   may be provided by replacing the hard slicer with a code

that provides a soft gain. An example of an inner code which can be used for this purpose is the Kerdock code.

Kerdock code vectors have a length typically defined as the number of bits per code vector. For purposes of describing the present invention, it is assumed that a code vector has a length of sixteen indicating that there are sixteen bits in each code vector. However, it should be understood that code vectors having different lengths may be used with respect to the present invention. For example, code vectors having a length of 64, 256, or more may be used with respect to the present invention.

It is known that there are 256 code vectors when the code vectors have a length of sixteen. If one of these 256 code vectors is properly chosen as a reference code vector, then there are 112 code vectors which have a distance of six from the reference code vector, there are 30 code vectors which have a distance of eight from the reference code vector, there are 112 code vectors which have a distance of ten from the reference code vector, and there is one code vector which has a distance of sixteen from the reference code vector. The code vector which has a distance of sixteen from the reference code vector is the complement

of the reference code vector. Distance is defined here as the number of bits which can be changed in one code vector before that code vector equals another code vector.

This reference code vector, the 30 code vectors which have a distance of eight from this reference code vector, and the complement (i.e., negative) of this reference code vector may be selected as a coset, and the reference code vector may be designated as the coset leader of the coset. Each code vector of these 32 code vectors has a complement in the coset. Accordingly, a coset contains first and second groups of code vectors, where each group contains sixteen code vectors, and where each code vector in the first group has a complement in the second group. Therefore, it is useful to envision a coset as containing sixteen code vectors, where each code vector can be either positive or negative.

The 256 code vectors may be similarly divided into seven more cosets, each having a coset leader, so that there are a total of eight cosets. The code vectors in each of these cosets are referred to as Kerdock code vectors.

A code vector may be transmitted by a transmitter 10 shown in Figure 1 so that it represents a number of data

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elements. A data element may be a bit or bits, a symbol or symbols, or another unit or units of information. The transmitter includes a Kerdock encoder 12, which encodes each byte (i.e., eight data elements) of data as a Kerdock code vector, and a modulator 14, which modulates the Kerdock code vector onto a carrier. A byte of data, for example, contains data elements b7 b6 b5 b4 b3 b2 b1 b0.

In encoding a data byte as a Kerdock code vector, the byte is partitioned such that one data element selects a sign (+ or -), three data elements select a coset leader, and four data elements select a Walsh function. For example, the data element b7 may be used to select the sign (+ or -), the data elements b6-b4 may be used to select the coset leader, and the data elements b3-b0 may be used to select the Walsh function. Because data elements b6-b4 comprise three data elements, they may be used to select one of eight coset leaders. Because data elements b3-b0 comprise four data elements, they may be used to select one of sixteen Walsh functions. The selected Walsh function is then mapped to one of the sixteen rows of the binary Walsh-Hadamard matrix. The binary Walsh-Hadamard matrix is a 16x16 matrix of ones and minus ones. Thus, data elements

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b3-b0 having a value 0000 correspond to a Walsh function
equaling 0, and this Walsh function is mapped to the first
row of the binary Walsh-Hadamard matrix. Similarly, data
elements b3-b0 having a value 0001 correspond to a Walsh

5   function equaling 1 which is mapped to the second row of the
binary Walsh-Hadamard matrix, and so on. The selected coset
leader and the selected matrix row are then vector
multiplied. That is, each data element of the selected
coset leader and its corresponding data element in the

10   selected matrix row are multiplied. The sign of the
multiplication result is changed if the data element b7
equates to a minus sign, and is not changed if the bit b7
equates to a plus sign.

As an example, let it be assumed that a data byte

15   10010001 is to be encoded as a Kerdock code vector. The
coset leader of coset 1 (cl1) is selected because the data
elements b6-b4 have a value of 001. The coset leader cl1,
for example, may have the following bit pattern:

cl1 = 1 1 -1 -1 1 -1 1 -1 1 -1 -1 1 1 1 1 1

The values of data elements b3-b0 can range from 0000 to
1111 corresponding to Walsh functions w0, w1, . . ., w15.
The data elements b3-b0 in the data byte 10010001 have a
value 0001 and, therefore, represent Walsh function w1 which

5   corresponds to the second row of the binary Walsh-Hadamard
matrix.   The following second row is selected as the Walsh
function w1:

w1 = 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1

The coset leader cl1 and the Walsh function w1 are vector

10   multiplied as (cl1)(w1) producing the following result:

(cl1)(w1) = 1 -1 -1 1 1 1 1 1 1 1 -1 -1 1 -1 1 -1

Finally, because the data element b7 is a one which
represents a minus sign, the result of (cl1)(w1) is
multiplied by -1 to produce the following Kerdock code

5   vector:

(-1)(cl1)(w1) = -1 1 1 -1 -1 -1 -1 -1 -1 -1 1 1 -1 1 -1 1

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This vector is shown graphically in Figure 2. Instead of performing the above calculations for each byte of data to be transmitted, the Kerdock encoder 12 can store in memory each of the possible Kerdock code vectors in a look-up table at an address corresponding to its associated data byte value so that the memory stores 256 Kerdock code vectors in all.

A receiver 20 receives each Kerdock code vector from the channel. The receiver 20 includes a demodulator 22 which demodulates the received signal to recover the transmitted Kerdock vector. The Kerdock code vectors at the output of the demodulator 22 are equalized in an equalizer 24 and are then applied to a Kerdock decoder 26 which decodes the received Kerdock code vectors in order to recover the transmitted data. The equalizer 24 may be implemented as a time domain filter which multiplies the received signal by a plurality of taps and which sums the multiplication results to produce an equalizer output.

The Kerdock decoder 26, which is shown more fully in Figure 4, includes eight multipliers 28-0, 28-1, . . ., 28-7 each of which multiplies the received Kerdock code vector by a corresponding one of the eight coset leaders

c10, c11, . . ., c17. These multiplications produce eight

vectors each having a length of sixteen. Each of eight

Walsh transforms 30-0, 30-1, . . ., 30-7 is performed on a

corresponding one of these eight vectors. The largest

5   correlation peak within the transform peak spectra produced

by the Walsh transforms 30-0, 30-1, . . ., 30-7 determines

the coset leader which was used to generate the transmitted

Kerdock code vector, the position of this peak within the

transform peak spectra determines the Walsh function which

10   was used to generate the transmitted Kerdock code vector,

and the sign of the peak determines the data element b7.

For example, if it is assumed that the transmitted

Kerdock code vector was generated using coset leader c11,

Walsh function w1, and sign of minus as described above,

15   Figure 5 shows exemplary outputs of the Walsh Transforms 30-

0, 30-1, . . ., 30-7. Because the largest peak (-16)

corresponds to coset leader c11 which in turn corresponds to

data elements b6-b4 having a value 001, because the largest

peak is the second peak within the transform peak spectra

20   and, therefore, corresponds to data elements b3-b0 having a

value 0001, and because the largest peak has a minus sign

which corresponds to the data element b7 having a value of

1, the Kerdock decoder 26 decodes the received Kerdock code vector as the byte 10010001.

The exemplary spectra produced by the Walsh Transforms 30-0, 30-1, . . ., 30-7 shown in Figure 5 assumes no noise and channel effects. In general, however, there are noise and other effects in the channel all of which will likely alter the spectral outputs of the Walsh Transforms 30-0, 30-1, . . ., 30-7 so that the difference in magnitude between the largest peak and the next largest peak will not be as large as shown in Figure 5. Indeed, the largest peak may not even correspond to the Kerdock code vector actually transmitted. Because of these possibilities, the equalizer 24 is controlled in such a way as to increase the likelihood that the largest peak will correspond to the Kerdock code vector actually transmitted.

Accordingly, a Kerdock encoder 32, which may be identical to the Kerdock encoder 12 of the transmitter 10, re-encodes the data from the output of the Kerdock decoder 26. The output of Kerdock encoder 32 is subtracted from the input to the Kerdock decoder 26 by a summer 34 to form an error vector e representing the difference between the transmitted Kerdock code vector as received and a Kerdock

code vector based upon the output from the Kerdock decoder
26.   The error vector e and a reliability weighting level r
are multiplied together by a multiplier 36.   Code gain is
provided by the Kerdock decoder 26.

5   The reliability weighting level r is used by the
multiplier 36 to scale the feedback represented by the error
vector e and is a quantized value depending upon Δ, which is
the difference between the absolute value of the Walsh
Transform output peak having the largest magnitude and the
10   absolute value of the Walsh Transform output peak having the
next largest magnitude.

          It is this Δ that determines the reliability of
the feedback error vector e.   Thus, a larger value of Δ
implies that the decoding implemented by the Kerdock decoder
15   26 is more reliable.   Accordingly, if the value of Δ is
large, the reliability weighting factor r is set to one or
nearly one so that most or all of the feedback error vector
e is used to adjust the equalizer 24 as discussed below.   On
the other hand, a value of Δ which is small implies that the
20   decoding implemented by the Kerdock decoder 26 is less
reliable because of noise such as burst noise in the
channel.   Noise in the channel can change the magnitude of

the dominant peak and also change its position within the transform peak spectra provided by the Walsh Transforms 30-0 to 30-7. Thus, if the value of Δ is small, the reliability weighting factor r is set to less than one so that less of

5   the feedback error vector e is used to adjust the equalizer 24. In this event, the taps of the equalizer 24 will not be significantly changed.

        Figure 6 shows in graph form an exemplary relationship between the difference Δ (shown along the x

10   axis) and the reliability weighting factor r (shown along the y axis). This relationship is stored in memory, permitting the Kerdock decoder 26 to read out the reliability weighting factor r based upon the difference Δ that it computes from the transform peak spectra provided by

15   the Walsh Transforms 30-0 to 30-7. The Kerdock decoder 26 supplies this reliability weighting factor r to the multiplier 36.

        The adjusted error vector re is supplied to an LMS (Least Mean Squares) adaptive control 38. Also supplied to

20   the LMS adaptive control 38 is a complex conjugated version of the output of the demodulator 22 derived by a complex conjugator 40. The LMS adaptive control 38 essentially

multiplies the complex conjugated version of the output of the demodulator 22 by the adjusted error vector re. The result of this operation may be multiplied by α which is less than one and which assures that changes to the tap

5   values of the equalizer 24 are made in incremental steps. The output of the LMS adaptive control 38 is added to the tap values used by the equalizer 24 in order to permit the Kerdock decoder 26 to accurately decode received Kerdock code vectors.

10   Accordingly, in the presence of substantial time varying noise, little or no change is made to the tap values of the equalizer 24 allowing the equalizer 24 to rely upon previously good channel estimates until the noise abates.

                Certain modifications of the present invention have been discussed above. Other modifications will occur

15   to those practicing in the art of the present invention. For example, as described above, the reliability weighting level r is a quantized value depending upon the difference between the absolute value of the Walsh Transform output

20   spectral peak having the largest magnitude and the absolute value of the Walsh Transform output spectral peak having the next largest magnitude. Alternatively, the reliability

weighting level r may be determined solely from the Walsh

Transform output spectral peak having the largest magnitude.

In this case, the Walsh Transform output spectral peak

having the largest magnitude might be used, for example,

5   only if such peak has a magnitude greater than a threshold.

As a still further alternative, the reliability weighting

level r may be based upon the difference between the square

of the absolute value of the Walsh Transform output spectral

peak having the largest magnitude and the square of the

10   absolute value of the Walsh Transform output spectral peak

having the next largest magnitude.

      Also, according to the description above, a Walsh

transform is used to determine a transmitted code vector.

However, other transforms may be used to determine the

15   transmitted code vectors.

      Moreover, as disclosed above, data is encoded

using Kerdock code vectors. Other types of code vectors,

however, may be used instead of Kerdock code vectors.

Multiple coding techniques also may be implemented to encode

20   the data.

      If transforms other than Walsh transforms are used

to determine a transmitted code vector, and if code vectors

other than Kerdock code vectors are used to transmit data, then reliability factors may be determined by methods other than those described above in order to weight the feedback error vector e.

5   In addition, the transmitter 10 and the receiver 20 are shown as comprising various blocks. Each of these blocks may be implemented as one or more discrete components, one or more integrated circuits, one or more programmable logic circuits or arrays, software, and/or the like.

10   In addition, the transmitter 10 and the receiver 20 may include other blocks as necessary to encode and decode data.

Furthermore, as disclosed above, the tap values of the equalizer 24 are adjusted by the LMS adaptive control 38. However, other controllers can be used in place of the

15   LMS adaptive control 38. For example, a zero forcing algorithm, a recursive least mean squares algorithm, a Kalman filter, and/or the like may be used to adjust the tap values of the equalizer 24.

Accordingly, the description of the present invention is to be construed as illustrative only and is for the

20   purpose of teaching those skilled in the art the best mode of carrying out the invention. The details may be varied

substantially without departing from the spirit of the
invention, and the exclusive use of all modifications which
are within the scope of the appended claims is reserved.